Multitasking with Graphical Encoding Visualization of Numerical Values in Virtual Reality

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Abstract

This study evaluates the influence of various visual representations of numerical values on users' ability to multitask in virtual reality. We designed a game-like VR simulation where users had to complete one main task while maintaining the status of other subtasks. Supplemental visualizations showed risk status of the subtask depending on experimental condition, with different visual data encodings: position, brightness, color, and area. We collected preliminary data (n=18) on participant performance during the experiment and subjective ratings afterward. The results showed that the intervention rate significantly differed between the four visual encodings, with the position-based version having the lowest rate.

Index Terms: Human-centered computing—Visualization; Human-centered computing—Virtual Reality

1 Introduction

In virtual reality (VR) and augmented reality (AR) applications, the user's view can be augmented with additional graphical representations of data values. Research in information visualization has shown significant differences in human perceptual ability to interpret values represented in different visual representations [3, 5, 6]. For example, visual differences in positions and lengths can be more accurately estimated than sizes, though numerical estimations of sizes can be judged more accurately than numerical representations through different shades of color or brightness. However, such research is typically limited to scenarios involving dedicated attention to the visualization. In our research, we study different types of visual representations for multitasking scenarios where the primary focus is interaction in a 3D environment.

Multitasking in 3D environments provides a complicated setting for monitoring status and balancing attention across locations while also interacting with objects within the environment, as has been studied in various domain contexts (e.g., [1, 2, 7]). Switching attention among tasks calls for high costs in terms of time and mental demand [1, 4]. In our research, we study how different visual encodings of numerical values can assist with situational awareness and status monitoring. We present an experiment using a VR multitasking task to compare four types of visual encodings (position, brightness, area, and color) to convey the numerical status of several activities in a multitasking VR environment.

2 Experiment

We conducted a preliminary experiment to study the effect of various visual encodings on users' performance while multitasking in VR. While balancing three separate tasks (see Figure 1), four different visual encodings represent the numerical status of two non-primary tasks. Figure 2 shows the four conditions for the visual encodings. These visualizations indicate to the user how close each of the two distractions is to fail. The primary task, shown in Figure 3 (*left*), asks the user to arrange colored blocks into a pattern. Once they successfully arrange the blocks, they earn points, and another pattern will show. The goal is to complete as many patterns as possible during the session time limit to obtain the highest score. However, while working on the primary task, participants must also maintain two distraction tasks, as shown in Figure 3 (middle and right).

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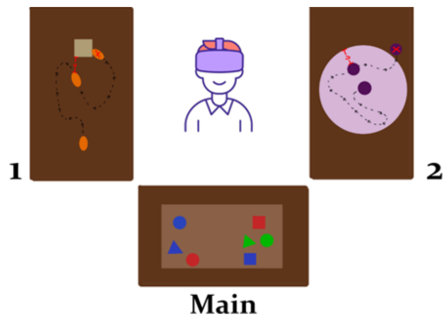

Figure 1: An overview of the VR environment where the user stands with the main task in front and subtasks 1 and 2 to the left and right.

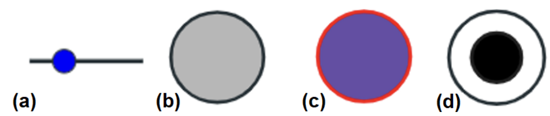

Figure 2: (a) Position encoding: As the slider gets closer to the right side, it is closer to failing. (b) Brightness encoding: As the circle gets darker and closer to matching the outer ring, it is closer to failing. (c) Color encoding: As the circle gets redder and closer to matching the outer ring, it is closer to failing.(d) Area encoding: As the inner circle expands to fill the outer ring, it is closer to failing.

Using a within-subject design, each participant completed the experiment in a 30-minute single session duration with a four-minute round per condition. Before starting the game, participants had two minutes to check their surroundings in the VR environment to familiarize themselves with the game. Our university's Institutional Review Board (IRB) approved the study.

The study had 18 participants (10 self-reported as male, 8 as female). We collected the following measures: **Success rate**: the number of block-building tasks completed per minute. **Failure rate**: the number of subtasks failed per minute. **Intervention rate**: the number of times the participant interacted with a subtask per minute. **Glance rate**: the number of times the user tilted their head to view the status display per minute. **Turn around glance rate**: the number of times per minute the user turned around to look at a subtask without intervention. Following the experiment, participants took a short questionnaire to rate each variation regarding noticeability, understandability, urgency, intrusiveness, and preference.

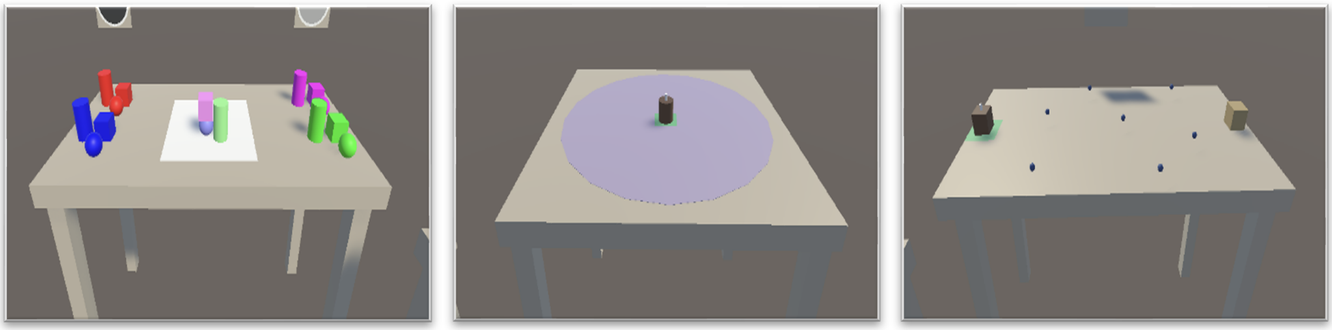

Figure 3: (a) Left: The primary **Block Building** task. Users pick up the blocks on the table's edge and place them into the pattern shown translucently in the center. (b) Middle: The **Escape** secondary task shows a small cylinder in the center of a large purple circle that moves around randomly. The user must prevent the cylinder from exiting the purple circle. (c) Right: The **Mouse and Cheese** secondary task is abstractly modeled based on a mouse (brown cube) trying to get to a piece of cheese (yellow cube). The user is responsible for protecting the "cheese" and ensuring the "mouse" does not get to it.

3 Results and Discussion

The results showed that position and area visual encodings were the most efficient in provoking participants to switch between the primary and secondary tasks with the lowest number of interventions. Position scored the lowest among the two encodings, as shown in Figure 4. In addition, both scored the highest for noticeability, understandability, and urgency. These results align with Cleveland and McGill's [3] visual encoding ranking, where position encoding is ranked best, and area is second (among our conditions) in providing accurate data encoding. Color and brightness ranked the least in noticeability and urgency; however, these two encodings are easier to perceive in peripheral vision. Surprisingly, brightness scored the highest under preference, and color came second, whereas position and area scored the lowest.

The results are not statistically significant to show whether any visual encodings were intrusive. However, we expected none to be intrusive because the heads-up display was fixed and did not interfere with participants' vision while interacting with the VR objects. Participants intervened more in the cases of using color and brightness encodings, indicating that these encodings may have been over-prompting to participants' responses.

The results were insignificant for whether the position or area visual encodings affected users' performance regarding the number of patterns they completed in the primary task and the number of failures they had with the secondary tasks. Our visual encoding design is simple; examining different design variations might produce different conclusions. Also, the results do not show whether they affect participant attention. We measured attention by tracking the times participants glanced over the cues and the secondary tasks themselves; the more times they glanced over the cues and the secondary task, the more they experienced a division in their attention.

While the results are preliminary, the findings motivate broader research of visual design implications on status monitoring and multitasking in VR and AR. For future direction, it would be worth examining different methods of visually integrating data displays as well as multimodal cues such as auditory and haptic feedback.

Figure 4: Friedman's test shows statistically significant results for the intervention rate χ^2 = 10.824, df = 4, p = 0.029. A post hoc Bonferroni shows a statistically significant difference between the control and position and between position and color.

Acknowledgments

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